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PROTECTIVE COATINGS AND SEALANTS FOR SOLAR APPLICATIONS

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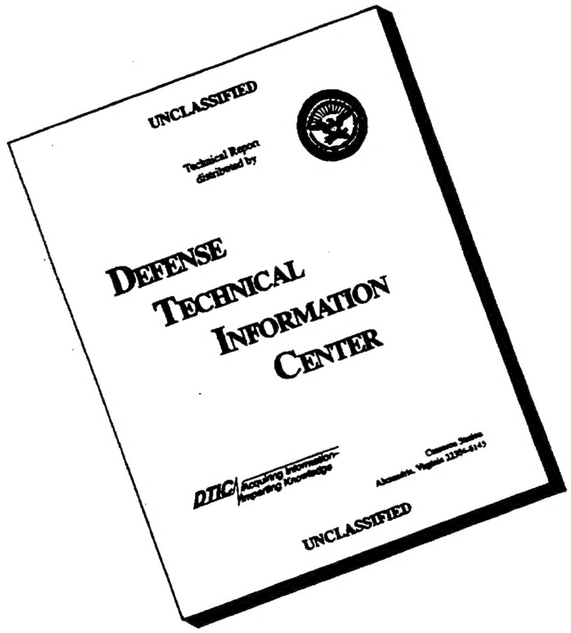

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PROTECTIVE COATINGS AND SEALANTS FOR SOLAR APPLICATIONS

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ABSTRACT

An aging study has been completed which evaluated a number of polymeric materials for potential use as 1) protective coatings for back surfaces of mirrors and 2) solar heliostat edge seals. These investigations were conducted in an artificial weathering chamber that accelerated thermal cycling. We observed the primary mirror failure mode to be silver corrosion resulting from moisture exposure. To increase mirror longevity in current heliostat designs, intimate bonding at all the composite interfaces is essential to minimize moisture pathways to the silvered surface. If any voids or delaminations are present, mirror degradation will eventually occur. Delaminations can also occur as the result of mechanical stresses brought about by mismatches in the various materials coefficients of thermal expansion. If good bonding cannot be achieved or mechanical stresses avoided, then improved moisture barriers must be designed to assure mirror longevity.

With good adhesion, a KRATON rubber was found to exhibit superior back surface mirror protection (12 months in environmental chamber with no corrosion). An ultraviolet stabilized butyl rubber appeared to be the best edge seal. All heliostats edge sealed with silicones showed silver corrosion which indicated either poor bonding or moisture permeation.

INTRODUCTION

Many current solar heliostat and flat plate collector designs which have been field tested show a vulnerability to long-term outdoor weathering (1). Therefore, the purpose of this investigation was to evaluate potential protective polymeric materials (i.e., coating, sealants) that could be used in various solar applications. Depending on the specific design, material weathering can occur in a variety of ways. For example, the reflectivity of silvered mirror heliostats can deteriorate with time in the presence of moisture (1,2). The mechanisms of silver deterioration are currently an area of conjecture (3). In flat-plate solar collectors high temperatures, humidity, ozone and ultraviolet (UV) radiation all contribute to aging processes which limit the lifetime of sealants, adhesives and gasket materials (4).

To exhibit long-term endurance, plastics and elastomers must offer excellent resistance to harsh outdoor environmental stresses while remaining compatible with hardware design. Inasmuch as the solar industry is in its infancy, virtually no new materials have been developed specifically for it. Thus, this study evaluates existing commercial materials for back-surface and edge-seal protection of solar mirror heliostats while indicating their advantages and limitations.

This work does not address the fundamental question of mirror corrosion mechanisms. Rather, our study was limited to visual observations of weathering effects upon products

exposed to extreme conditions in an environmental test chamber. The principal parameters investigated were 1) the materials' ability to protect silvered mirrors from moisture and 2) the effect of mechanical stress (coefficients of expansion mismatches) due to temperature-humidity cycling.

MATERIALS

Back Surface - Materials examined for the protection of the back surface of mirrors were: 1) ESTANE 5714 (a polyurethane) from B. F. Goodrich, 2) Pro Seal 890 (a polysulfide) from Essex Chemical Corp., 3) SARAN (polyvinylidene chloride) from Dow Chemical Co., and 4) KRATON (a styrene-butadiene block copolymer) from Shell Chemical Co. The ESTANE 5714 was dissolved in tetrahydrofuran, brushed on and then baked-out (to remove solvent) for 3 hours at 71°C. The Pro Seal 890 was compounded according to vendor instructions, brushed on, air dried for 6 hours followed by a 16 hour, 96°C cure. The SARAN was dissolved in a 65/35 tetrahydrofuran-toluene mixture and brushed on, followed by a 16 hour, 71°C bake. The KRATON was dissolved in toluene and either brushed or sprayed on. The concentration of KRATON had to be varied according to the method of application. Following application, a 3 hour, 71°C bake was applied. All coatings were placed on 4" x 4" x 1/8" Gardner mirrors which included the Pittsburgh-Plate Glass protective gray paint (PPG 44409).

Edge Seals - The edge seals employed in this study were DC-790 and DC-738 from Dow Corning, GE 1200 from General Electric; all three are silicones. One butyl rubber sealant, Adcoseal B-100 was supplied by Adhesive Development and Chemical Operations, Inc. All these sealants, one-part systems dispensed from a prepackaged caulking tube are used extensively by the construction industry.

Test specimens were prepared by bonding a 4" x 4" x 1/8" Gardner mirror to an appropriate substrate with EC-3549 (amine cured polyurethane from 3M Co.) and then sealed around the mirror edge with a bead of the respective sealants. Since the sealants are one part systems, they were allowed to air cure for 2 weeks. At the time of this testing an optimum substrate had not been selected; thus, several substrates were evaluated in conjunction with the edge seal. Substrates included in this test were: 1) cellular glass (Solaramics Co.), 2) polystyrene foam (Dow Corning), 3) polystyrene foam with added butyl rubber pad, 4 and 5) paper honeycomb seal with epoxy-fiber glass and melamine respectively, 6 and 7) sine-wave fiberglass sealed with epoxy-fiberglass and melamine respective (Items 4-7 were supplied by Parabolite Inc.). Two control samples were also fielded; one was simply a sample of Gardner mirror, the other was a Gardner mirror containing the EC-3549 adhesive on the back to determine compatibility. Both Gardner control mirrors possessed the PPG-44409 gray paint.

EXPERIMENTAL

Artificial weathering was conducted in a Conrad, Inc., Environmental Test Chamber. The chamber was programmed to cycle from -29°C to 50°C three times during 24 hours, a cycle consists of a two hour hold at each temperature extreme with a two hour ramp in between. The humidity was measured at 82% at 50°C and 50% at 7°C, thus a distinct freeze-thaw cycle occurred when a test passed through 0°C (5). The number of freeze-thaw cycles in one month equal a one year Albuquerque, New Mexico weather exposure with the temperature variation reflecting the highest and lowest temperature during the last 50 years. This chamber does not incorporate UV radiation as an environmental stress.

RESULTS AND DISCUSSION

Back Surface Protection

As mentioned, one of the primary factors contributing to mirror deterioration is water in its various forms. (1) In an effort to retard the deterioration of silvered mirrors, several different commercial polymeric materials were evaluated. Our selection was governed by the materials' hydrophobic nature or known use in weather resistant applications. Specifically, these choices were: 1) a polyurethane, 2) a polysulfide, 3) polyvinylidene chloride and 4) a styrene-butadiene copolymer (hydrocarbon). One must realize that any polymeric coating will permeate water in time, consequently predicting "protected" mirror lifetimes becomes very difficult. Since these coatings were for back surface protection, UV stability and abrasion resistance were not of concern. The coatings were evaluated on: 1) mirrors which contained only the silver and standard sacrificial copper layer and 2) mirrors having the familiar protective gray paint. The first experiment was designed to eliminate the contributing effect of gray paint.

Table I lists the coatings and empirical results. The coatings will be discussed in order of their increasing effectiveness. The polysulfide (Pro Seal 890) almost immediately attacked the silver. This illustrates one of the first problems with material selection, materials compatibility. The free sulfur in this class of compounds was simply incompatible with silver. In fact, the painted mirror showed evidence of attack only a few days after the unpainted

sample. The SARAN coating began to peel after 7 days indicating very poor adhesion. This peeling exemplifies another critical problem associated with protecting any surface from moisture, the necessity for intimate adhesion between coating and substrate. We believe a key to mirror longevity is the integrity of the various bond interfaces. If there is intimate bonding, only molecular water permeates to the silver and negligible damage occurs (6). Even though SARAN has outstanding moisture resistance, if poor bonding exists then a void delamination can occur. As a result, water will congregate and mirror degradation follows by whatever corrosion mechanism. The polyurethane (ESTANE 5714) appeared to offer some degree of protection; however, with time it also began to peel, followed by mirror corrosion. The styrene-butadiene copolymer (KRATON 1101) afforded the greatest protection, exceeding all other coated samples in durability. Assuming good bonding, this result was not unreasonable to expect since the coating was a hydrocarbon and would not be expected to have an affinity for water. These results were encouraging enough to employ the coating as an additional moisture barrier on the back of some sagged glass panels (24" x 63") for field testing. A spray coating of 0.127 cm (5 mils) of KRATON 1101 was applied to the mirrors and edge sealed with a lead tape (3M Scotch 421). These mirrors have been in the field for over 5 years with virtually no sign of deterioration.

From this limited study, hydrocarbon coatings with good bonding characteristics would be the materials of choice when attempting to protect against moisture. These materials are not intended as substitutes for the traditional gray paint protective coating, but simply as added moisture barriers. Although not tested, more recent KRATON products have been marketed which because of their improved UV and upper temperature capability may be better choices (e.g., KRATON G-1650, 1652) for these applications than KRATON 1101.

Edge Seal Protection

Heliostats for long term field use will probably require edge seal protection. Materials for this application must have outstanding weatherability (in particular UV resistance) since in contrast to back surface protective coatings, they are directly exposed to the elements. A review of existing candidate edge seal materials indicates that silicones possess the best overall weathering properties. Inasmuch as there are no edge seals specifically designed for solar hardware, the following commercially available building sealants were selected for evaluation: silicones from Dow Corning (DC-790, 738), General Electric (GE 1200) and a butyl rubber termed Adcoseal B-100. Some understanding of the chemistry of these compounds is required to assure compatibility with the heliostat design. Most silicone building sealants are one component systems that rely on moisture to cure. As a result they eliminate by-products which can be potentially detrimental to the longevity of aluminum

or silver mirrors. The DC-790 liberates amine products, DC-738 emits alcohol, GE 1200 yields acetic acid and butyl rubber outgasses toluene (sealant solvent). By-products such as amines and acetic acid would be considered incompatible with silvered mirrors. Construction of the model heliostats and the substrates involved can be found in the materials section. These model heliostat reflector segments along with controls were placed in the temperature-humidity cycling chamber for evaluations.

Tables 2 through 4 summarize the results of this 12 month aging study. Before discussing the individual mirror modules, some generalizations and qualifying remarks should be made. A brief scan through these tables will show that all the composite mirror systems suffered deterioration except the butyl edge seal on the butyl rubber pad (see Table 2). Figures 1-16 show that degradation can assume an almost infinite number of forms. For this photographic record, exposures were made so as to highlight degraded areas; thus some figures are lighter or darker depending on the situation. Double images are the result of a surface blemish that could not be removed. Degradation was found to occur as a variety of pitting or spots, silver delaminations, dendritic growths, color variations and many forms of shadowing or fogging. Earlier beliefs that deterioration would begin at the edges and propagate inward are not necessarily true; degradation appeared to start at virtually any location with no systematic pattern.

Cellular glass was considered a promising heliostat substrate because the coefficients of thermal expansion between the mirror and substrate were matched. Test mirrors were bonded and sealed with the respective silicone sealants (see Table 2) and aged. Within three months all the tested samples crumbled. The substrates became filled with water and crumbled during the freeze-thaw cycling due to coefficient of expansion mismatches between the water and glass (5). Obviously to use a cellular glass substrate, it must be sealed. To this end, various protective coatings have been painted on the cellular glass. A KRATON coated cellular glass appears to be a promising candidate. This sample showed no evidence of crumbling after 12 months in the environmental chamber (7).

The use of polystyrene foam as a heliostat substrate has been a popular choice because of low cost and ease of fabrication; in fact this was the McDonnell-Douglas choice in their original Barstow pilot plant design. As described in Table 2 and shown in Figures 1-3 varying forms of degradation or corrosion occur regardless of what edge seal was employed. The DC-790 and GE 1200 were anticipated to be inferior because of their outgassing products (amines, acetic acid), yet the DC-738 which eliminates a relatively benign by-product (methanol) was just as ineffective. Either the silicone edge seals permeate moisture at a rate higher than anticipated or there is poor bonding at the various sealant interfaces. Once the moisture has diffused in between the mirror and substrate it becomes trapped. Once

trapped, the water cannot escape since the module cannot "breathe," that is moisture cannot freely condense and evaporate during thermal cycling. Consequently, moisture can freeze and the resulting expansion can cause further delaminations thereby allowing more moisture penetration. At higher temperatures the trapped water can lead to chemical degradation. Post-mortem examination of the module shown in Figure 3 revealed that the adhesive (EC-3549) to polystyrene foam interface was highly pitted. The corrosion observed virtually replicates the foams cellular structure. As a result of the cellular structure, there are literally hundreds of voids where moisture can diffuse, become trapped and cause mirror corrosion. Again, the presence of moisture points out the importance of bond integrity throughout these composite structures which includes the following interfaces: silver to glass, gray paint to the copper-silver layer, adhesive to gray paint and adhesive to substrate. If there is not intimate contact at each interface a void or delamination results, creating an area where harmful entities (e.g., water) can diffuse and initiate degradation. Nonbonding at these interfaces can occur in a variety of ways for example, poor adhesive applications, unclean surfaces, or poor process control. Because of thermal expansion mismatches, these non-bonded areas could increase in size during thermal cycling.

One of the better heliostat sealants was found to be a butyl rubber, Adcoseal B-100 (see Table 2 and Figure 4). This module incorporated a design modification; a 1/16" butyl rubber pad bonded between the mirror and the polystyrene foam substrate. The module looked extremely good after 12 months accelerated aging. A sealant of this type must be used with some degree of caution because butyl rubbers are not normally as thermally stable or UV resistant as silicones.

The paper honeycomb substrates sealed with either epoxy-fiberglass or melamine all showed some form of mirror degradation after 6 months and increased deterioration at 12 months (see Table 3 and Figures 5 and 10). The same explanation for the degradation in the polystyrene modules apply to this test design. Post-mortem examination of some of the modules again showed areas of poor bonding which resulted in moisture pathways and subsequent mirror corrosion. It is virtually impossible to apply a uniform adhesive layer over a large surface and obtain a void free glue line. Thus, with the sandwich heliostat structures being evaluated for solar applications, void free glue lines will always present a problem. Furthermore, it was interesting to note the fingerprints on various mirror samples (e.g., Figure 5). These fingerprints must have happened during mirror manufacture, since the mirrors contained the protective gray paint prior to our assembling the modules. Fingerprints prevent good silver to glass bonding and create degradation sites.

The sine wave fiberglass substrates sealed with either epoxy-fiberglass or melamine exhibited mirror deterioration after 6 months with increased degradation at 12 months (see Table 4 and Figures 11-16). Figures 11 and 15 are samples in which accidental impacts led to cracks. No deterioration was noted around the crack shown in Figure 11, whereas the sample in Figure 15 exhibited considerable pitting along the crack edges. In the first instance the bonding integrity of the silver and gray paint must still be substantial to preclude any silver degradation. In the latter sample, the bonding must have been weakened from the impact resulting in degradation. Post-mortem examination of the modules shown in Figures 11 and 12 dramatizes the degradation effects attributed to thermal expansion mismatches in sandwich heliostat structures. The sine wave ribs are perpendicular to the mirror surface and work against the mirror during thermal cycling causing debonding in the immediate contact area. This phenomenon provides a pathway for moisture to enter. Notice how the corrosion pattern replicates the sine wave structure. Mirror longevity is just as much a function of heliostat design as is material selection.

Observe the two control samples that were included in the aging study (see Table 3 and Figures 15-16). The Gardner mirror without any protection showed only a slight amount of pitting after 12 months. Survival of this mirror with a minimal amount of damage was attributed to its ability to "breathe". Moisture was not trapped as postulated in the

other composite heliostat designs. The control which was coated with the adhesive, EC-3549, showed evidence of deterioration (spotting, shadows) after 6 months. This corrosion suggests incompatibility between the adhesive and silver. The EC-3549 is a polyurethane adhesive cured with an amine. According to a literature source (8), the basicity of an amine in the presence of moisture can result in silver deterioration. Therefore, we could not really evaluate the effectiveness of the respective edge seals because material incompatibilities, nebulous bonding and heliostat designs appeared to have a greater bias on the results than edge seal selection.

Finally, although not specifically included in this study, a factor that bears mentioning is that different mirror manufacturers employ different protective gray paints. Thus, mirrors from different manufacturers aged similarly to those discussed above have shown varying amounts of longevity. For example in our test chamber, Gardner mirrors appear to age with less corrosion than previously aged Buckmin mirrors. The primary difference between the two products was the protective gray paint.

SUMMARY AND CONCLUSION

The findings in this aging study resulted in the following conclusions which should have a bearing on future heliostat designs:

1. Edge Seal choices seemed of minor importance compared to the overall module design and bonding integrity. As shown earlier, poor heliostat designs (i.e., polystyrene foam and sine wave fiberglass substrates) resulted in moisture entrapment and diffusion pathways which lead to rapid mirror deterioration. Although they age well (little chemical degradation), silicone edge seals appear to bond poorly and/or permeate moisture easily.
2. To minimize moisture diffusion pathways either a better barrier is needed, that is, an improved design or to assure the integrity of the various bond interfaces (i.e., edge seals to substrates, silver to glass, etc.). The former appears to be achievable in the time frame studied by use of a butyl rubber pad and sealant. The latter parameter has no easy solution. For example, the silver to glass bond would probably require some fundamental studies to optimize this interface.
3. Mirror corrosion was manifested by a variety of forms such as pitting, spotting, shadowing or fogging, delaminations, discolorations and growths with no particular pattern. Efforts were not made to elucidate corrosion mechanisms, yet we believe the first step in the degradation process is a delamination or creation of a void

area at some critical interface. This void area allows harmful reactants (e.g., water) to collect, thereby precipitating degradation. Whether this delamination is stress induced (thermal cycling) or the result of initially poor bonding is a matter of conjecture.

4. Compatibility of various materials in these heliostat designs is an important consideration which if properly addressed can add longevity to the system. For example, our data indicates a current adhesive, EC-3549, contributes to mirror degradation due to the presence of an amine curing agent. Thus, a different adhesive such as a polyol cured urethane seems appropriate. Another example, even though all the composite modules exhibited degradation for one reason or another, a silicone edge seal which outgasses a relatively benign by-product like alcohol would be a logical choice as an edge sealant. In general, butyl rubber sealants were superior to silicones, providing a UV stabilized product is used.

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TABLE 1. BACK SURFACE MIRROR PROTECTIVE COATINGS OBSERVATIONS

MATERIAL	NO GRAY PAINT	GRAY PAINT PROTECTION*
PRO SEAL 890	SILVER ATTACKED AFTER 4 DAYS	SILVER ATTACKED AFTER 7 DAYS
SARAN	COATING BEGAN TO PEEL IN 7 DAYS, SILVER CORROSION BEGAN SHORTLY THEREAFTER	PEELING AFTER 7 DAYS
ESTANE 5714	DETERIORATION AFTER 2 MONTHS	COATING PEELING AFTER 4 MONTHS
KRATON 1101	SOME PITTING AND DETERIORATION AFTER 6-8 MONTHS	AFTER 12 MONTHS NO EVIDENCE OF DETERIORATION
CONTROL MIRROR NO PAINT	DETERIORATION AFTER 7 DAYS	---
CONTROL MIRROR WITH PAINT	---	EVIDENCE OF ATTACK AFTER 8 MONTHS, PITTING

* The mirrors studied were coated with PPG-UC-44409 gray paint.

TABLE 2. MIRROR MODULE AGING OBSERVATIONS (4" x 4" x 1/8" MIRRORS)

MODULE DESIGN	1 MO.	3 MO.	6 MO.	12 MO.
FOAMED GLASS				
DC-790	OK	FOAM CRUMBLED		
DC-738	OK	FOAM CRUMBLED		
GE-1200	OK	FOAM CRUMBLED		
POLSTYRENE FOAM				
DC-790	OK	OK	SLIGHT EDGE EFFECTS	FINGER PRINTS, SHADOWS, BLACK PITTING
DC-738	OK	OK	FINGERPRINT OTHER-WISE OK	NUMEROUS FINGER-PRINTS, SOME SMALL PITS
GE-1200	OK	OK	SLIGHT EDGE EFFECTS, SHADOWS, PITS	INCREASED EDGE EFFECTS, SHADOWS, PITTING
ADCOSEAL B-100	OK	OK	SLIGHT PITTING	TRAIL OF LIGHT PITTING ACROSS MIRROR
ADCOSEAL B-100 1/16" Butyl Pad Backing	OK	OK	OK	OK

TABLE 3. MIRROR MODULE AGING OBSERVATIONS (4" x 4" x 1/8" MIRRORS)

MODULE DESIGN	1 MO.	3 MO.	6 MO.	12 MO.
PAPER HONEYCOMB (EPOXY-FIBERGLASS SEALED)				
DC-790	OK	OK	SLIGHT PITTING AROUND EDGES	SHADOWING, PATTERNED PITTING
DC-738	OK	OK	LIGHT SHADOWING	SHADOWING, HEAVY PITTING
GE-1200	OK	OK	SMALL PITS AND SHADOWS	PITTING, FINGERPRINTS SOME SHADOWS
PAPER HONEYCOMB (MELAMINE SEALED)				
DC-790	OK	OK	SOME SPOTTING, SHADOWS	EDGE EFFECTS, SPOTTING FINGER-PRINTS
DC-738	OK	OK	SOME PITTING, LARGE SHADOWS	INCREASED PITTING, LARGE SHADOWS
GE-1200	OK	OK	TWO SMALL SPOTS	NUMEROUS SPOTS, THREE LARGE SPOTS WITH BREAKTHRU

TABLE 4. MIRROR MODULE AGING OBSERVATIONS (4" x 4" x 1/8" MIRRORS)

MODULE DESIGN	1 MO.	3 MO.	6 MO.	12 MO.
SINE WAVE FIBERGLASS (EPOXY-FIBERGLASS SEALED)				
DC-790	OK	OK	PITTING, SHADOWS	SEVERE SHADOWING
DC-738	OK	OK	SHADOWING, PITTING	SEVERE DETERIORATION
GE-1200	OK	CORNER CRACK	SHADOWING, LIGHT PITTING	BLACK PITTING, SHADOWS
SINE WAVE FIBERGLASS (MELAMINE SEALED)				
DC-790	OK	OK	SMALL SPOTS	MIRROR CRACKED, SPOTS AROUND CRACK, OTHER SPOTS
DC-738	OK	SLIGHT SPOTTING	HEAVY PITTING, EDGE EFFECT	LARGE SPOTS, EDGE EFFECTS, SHADOWS
GE-1200	OK	OK	SMALL SPOTS	SPOTTING WITH ONE LARGE SPOT
CONTROL-GARDNER MIRROR, NO PROTECTION	OK	OK	SLIGHT PITTING	NO CHANGE
CONTROL-GARDNER MIRROR, EC-3549 ADHESIVE	OK	OK	FINGERPRINTS, SLIGHT PITTING AND SHADOWING	SLIGHT WORSENING OF PREVIOUS EFFECTS

FIGURE 1

POLYSTYRENE FOAM

ADHESIVE : 3M's EC-3549
EDGE SEAL : DOW CORNING 790 SEALANT
TIME AGED : 12 mos

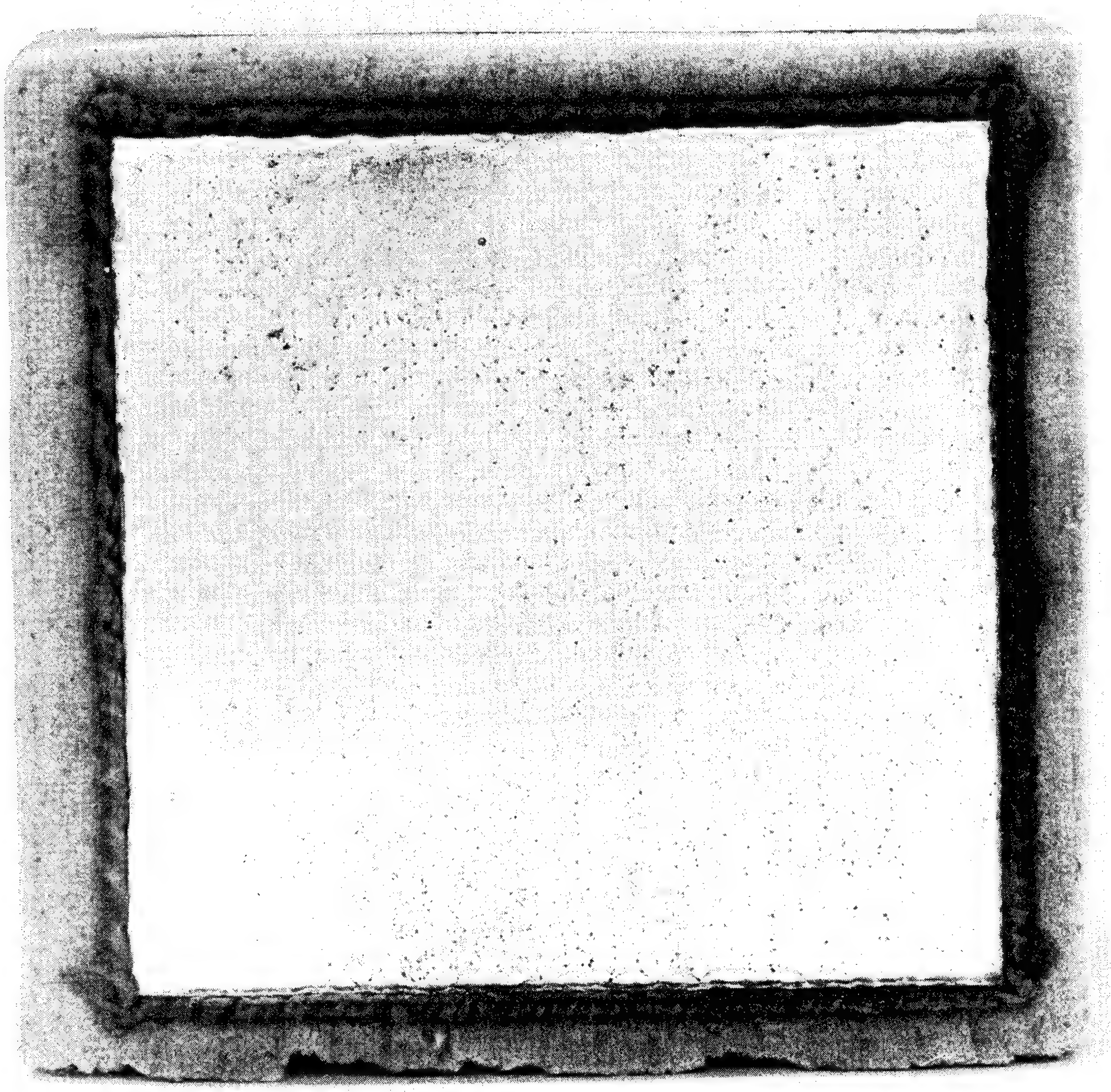
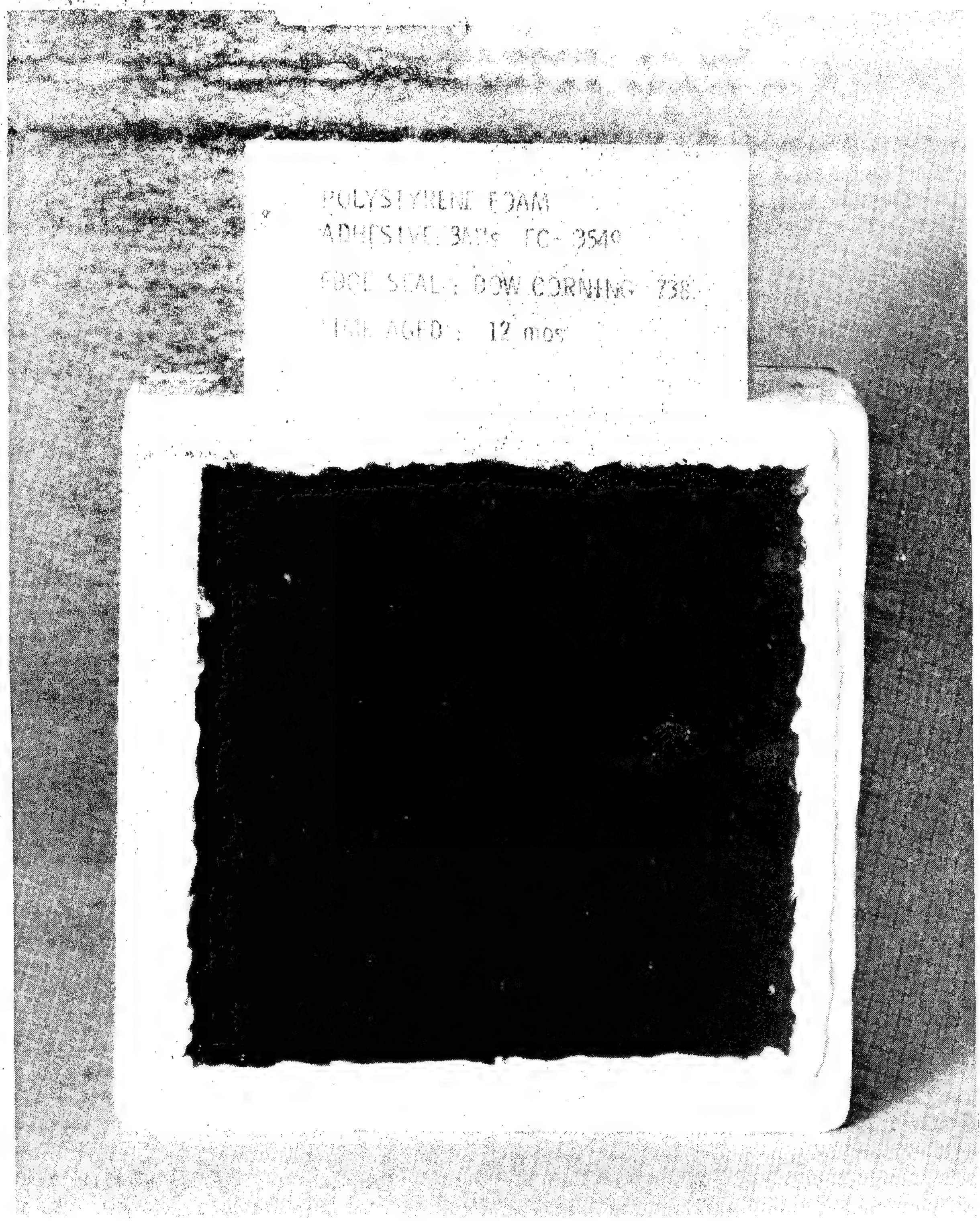


FIGURE 2



POLYSTYRENE FOAM
ADHESIVE: 3M's EC-3549
FACE SEAL: DOW CORNING 738
TIME AGED: 12 mos

FIGURE 3

POLYSTYRENE FOAM

ADHESIVE : 3M's EC- 3549
EDGE SEAL : GE 1200 CONSTRUCTION SEALANT
TIME AGED : 12 mos.

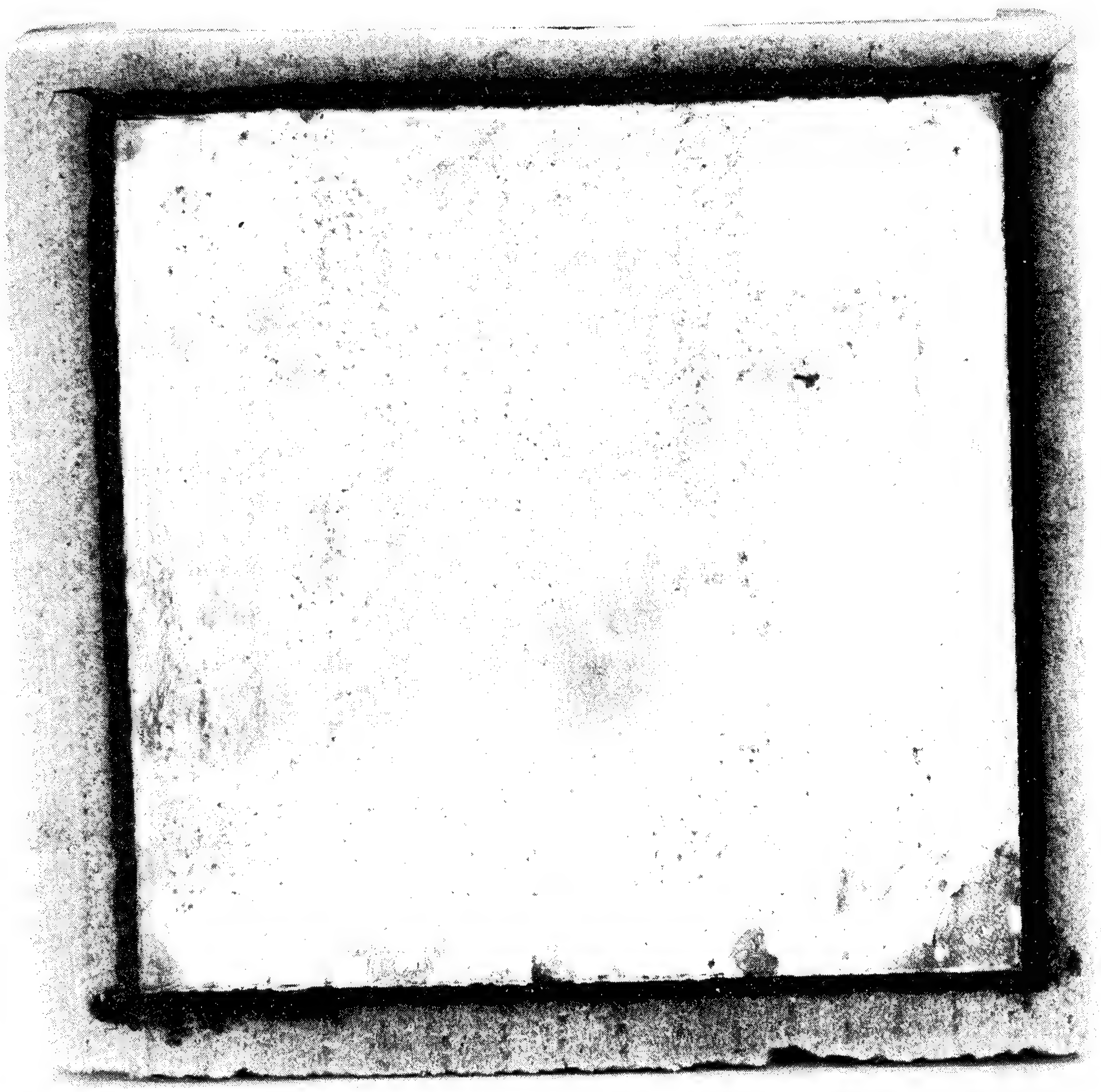
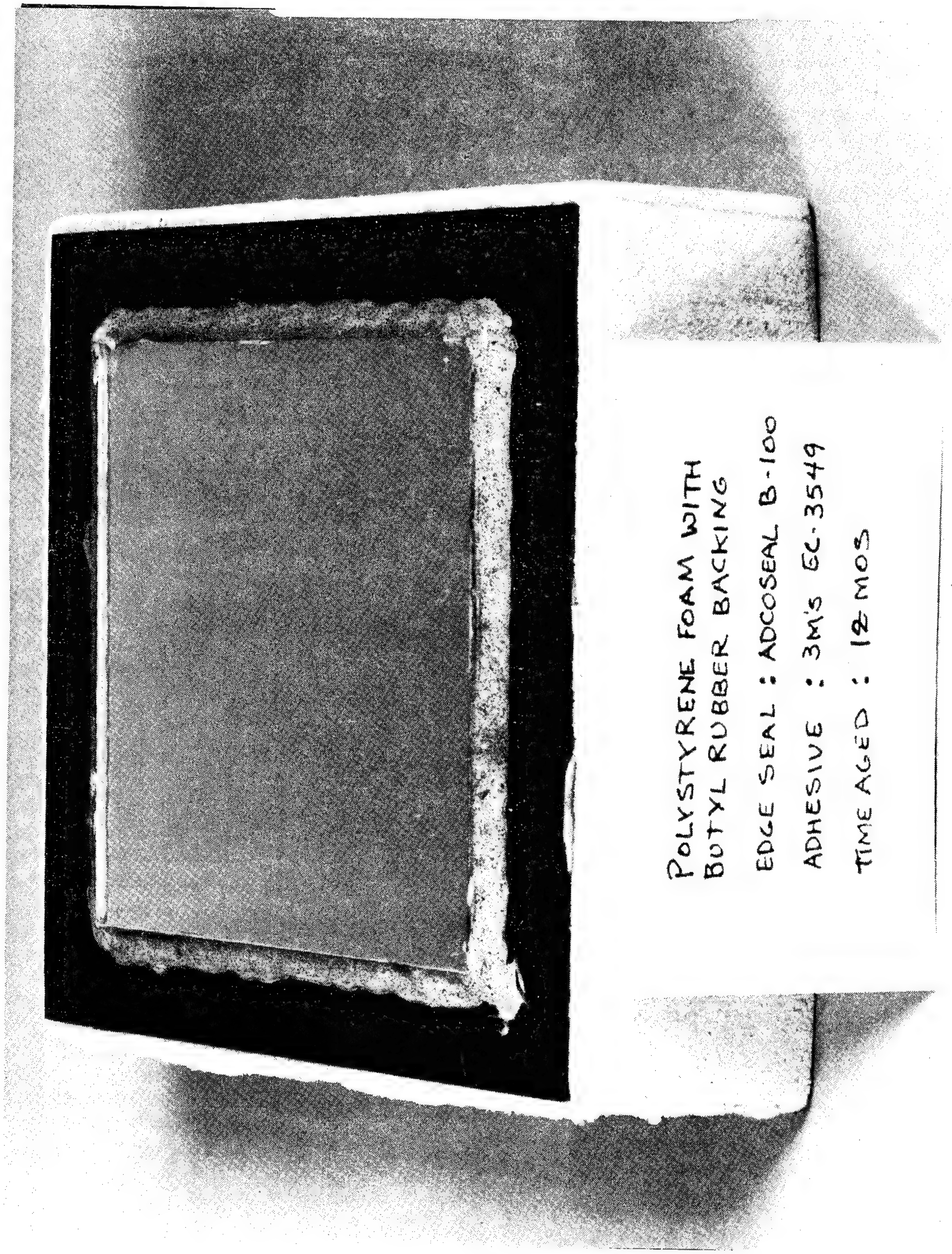


FIGURE 4


POLYSTYRENE FOAM WITH
BUTYL RUBBER BACKING
EDGE SEAL : ADCOSEAL B-100
ADHESIVE : 3M's EC-3549
TIME AGED : 12 MOS

#10

FIGURE 5

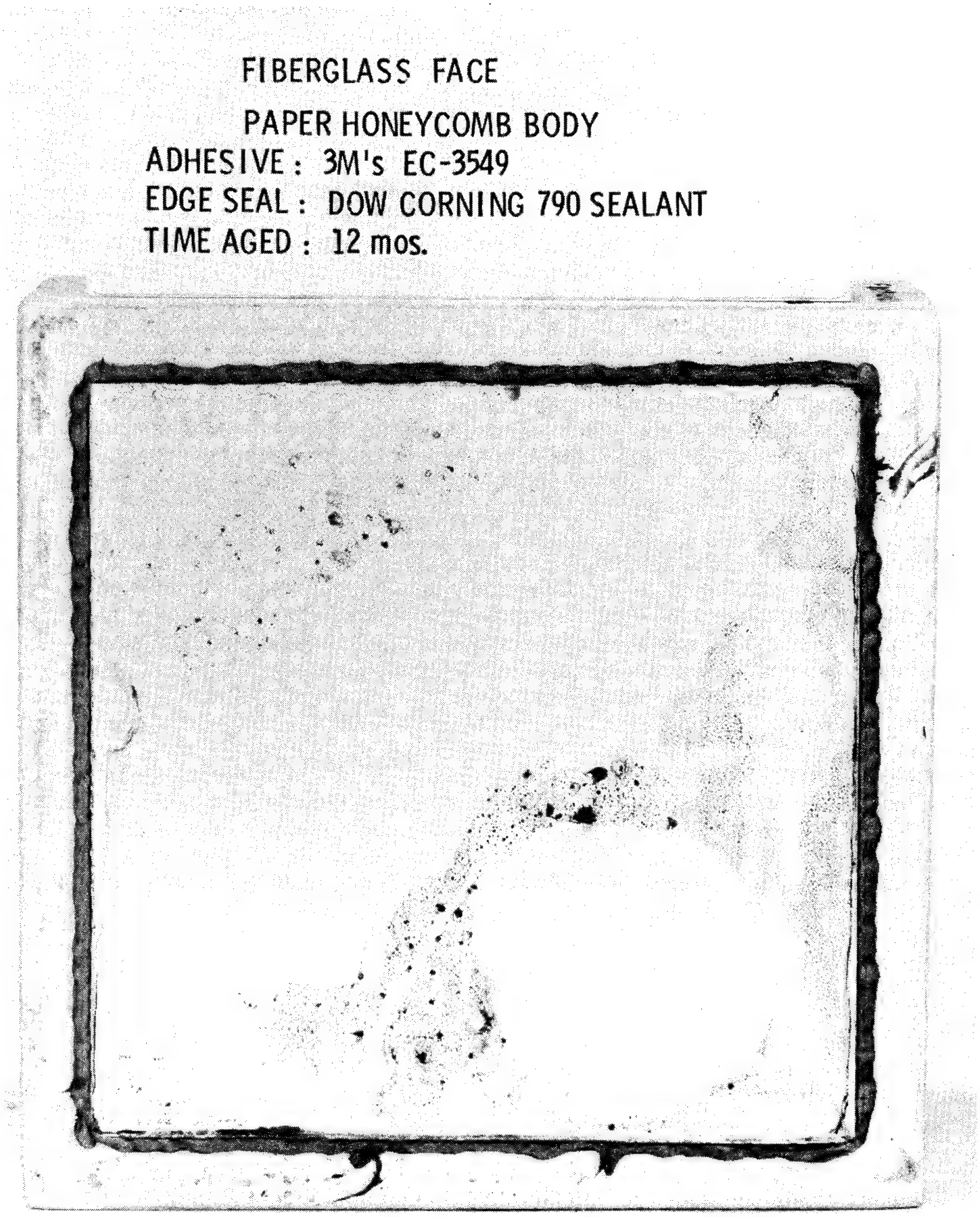

FIBERGLASS FACE
PAPER HONEYCOMB BODY
ADHESIVE: 3M's EC-3549
EDGE SEAL: DOW CORNING 790 SEALANT
TIME AGED: 12 mos.

FIGURE 6

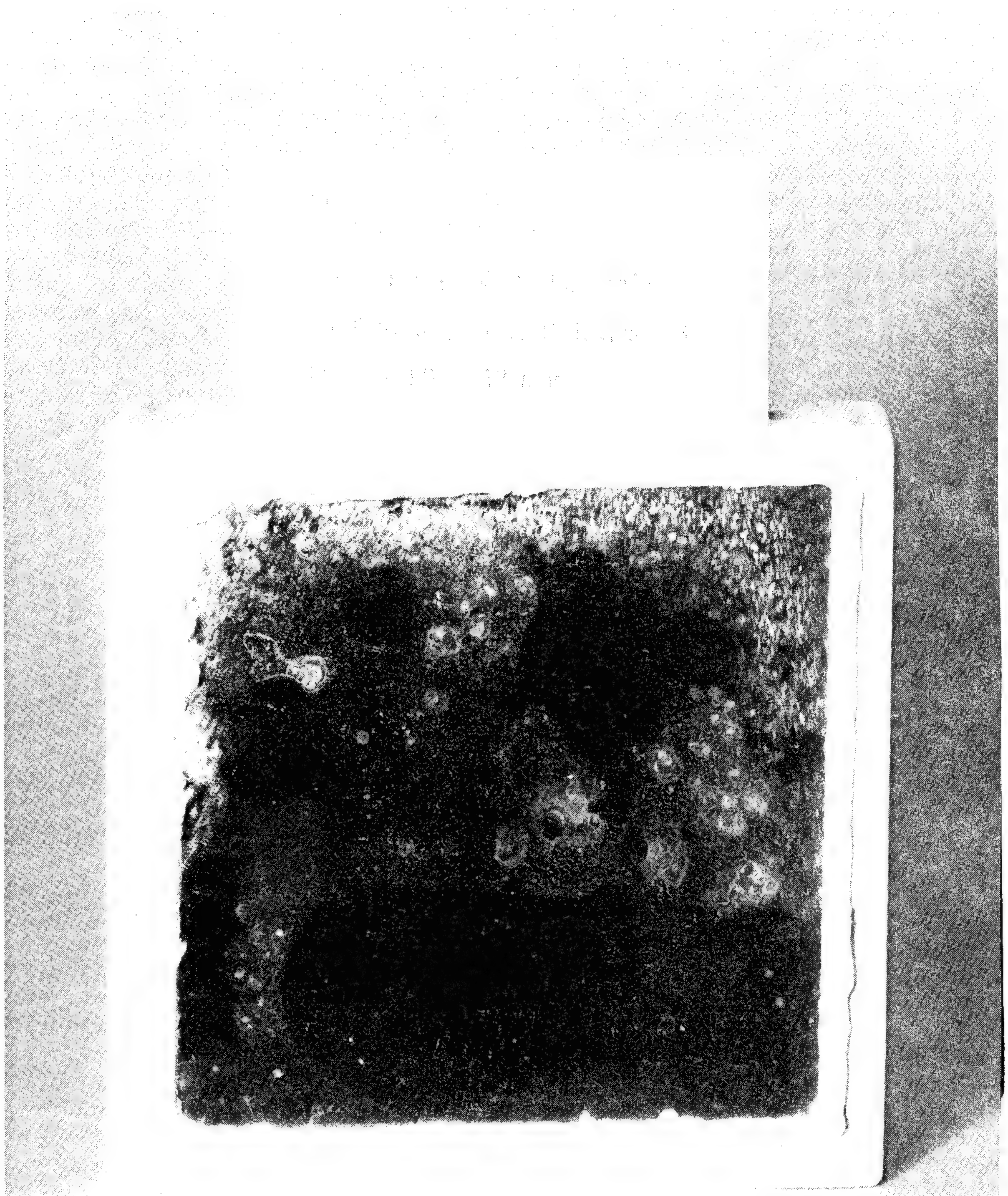


FIGURE 7

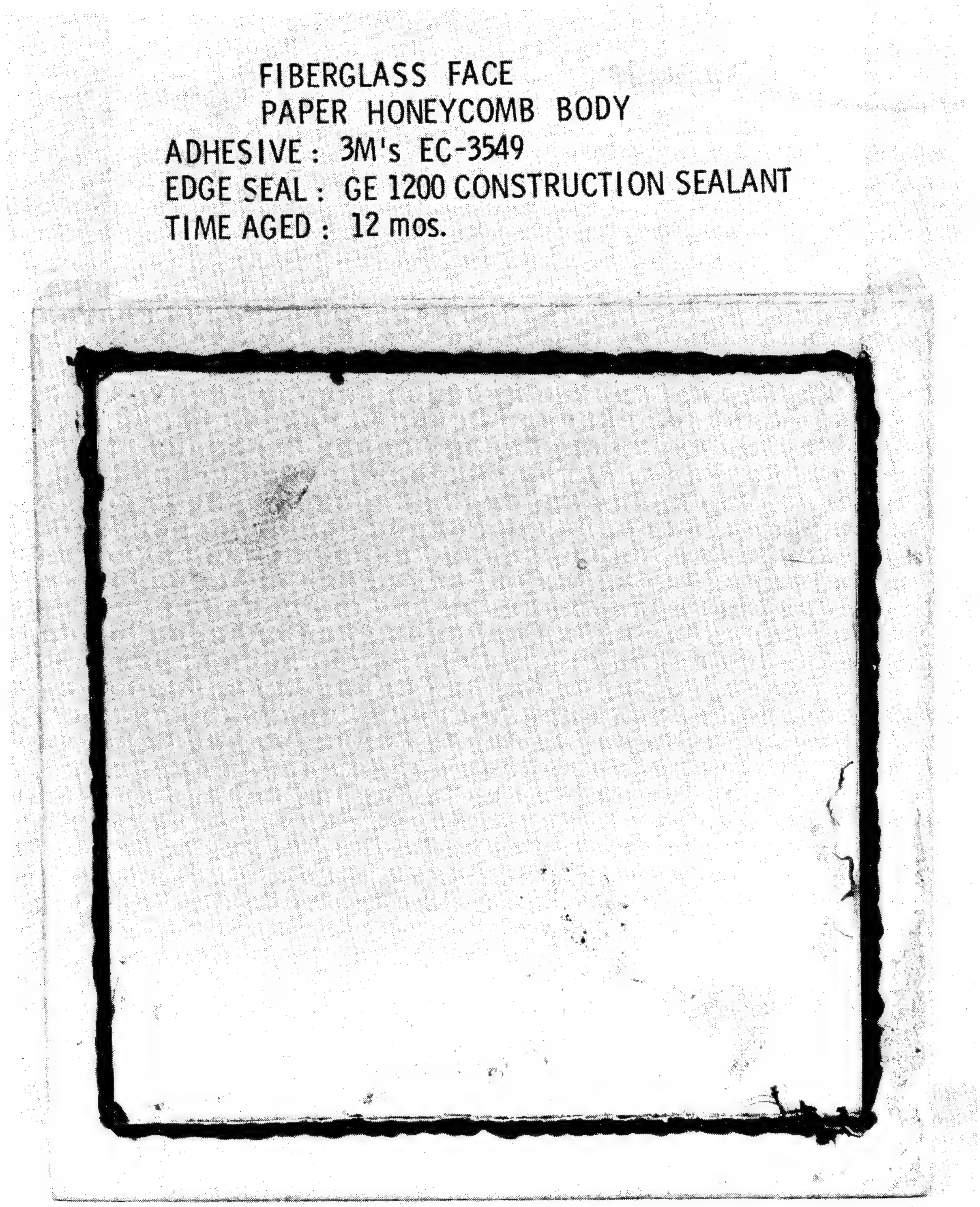

FIBERGLASS FACE
PAPER HONEYCOMB BODY
ADHESIVE: 3M's EC-3549
EDGE SEAL: GE 1200 CONSTRUCTION SEALANT
TIME AGED: 12 mos.

FIGURE 8

MELAMINE FACE
PAPER HONEYCOMB BODY

ADHESIVE: 3M's EC-3549
EDGE SEAL: DOW CORNING 790 SEALANT
TIME AGED: 12 mos.

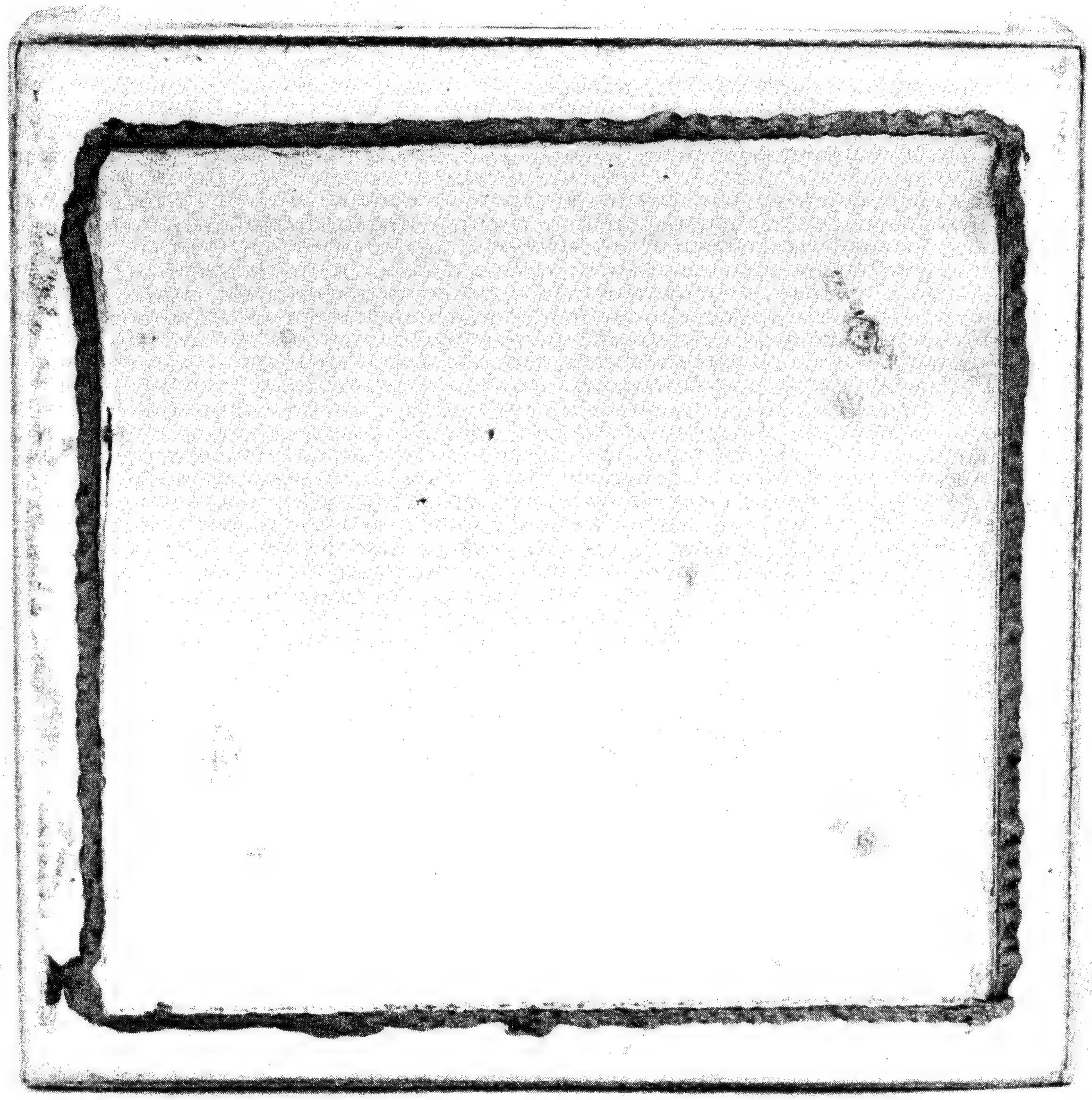


FIGURE 9

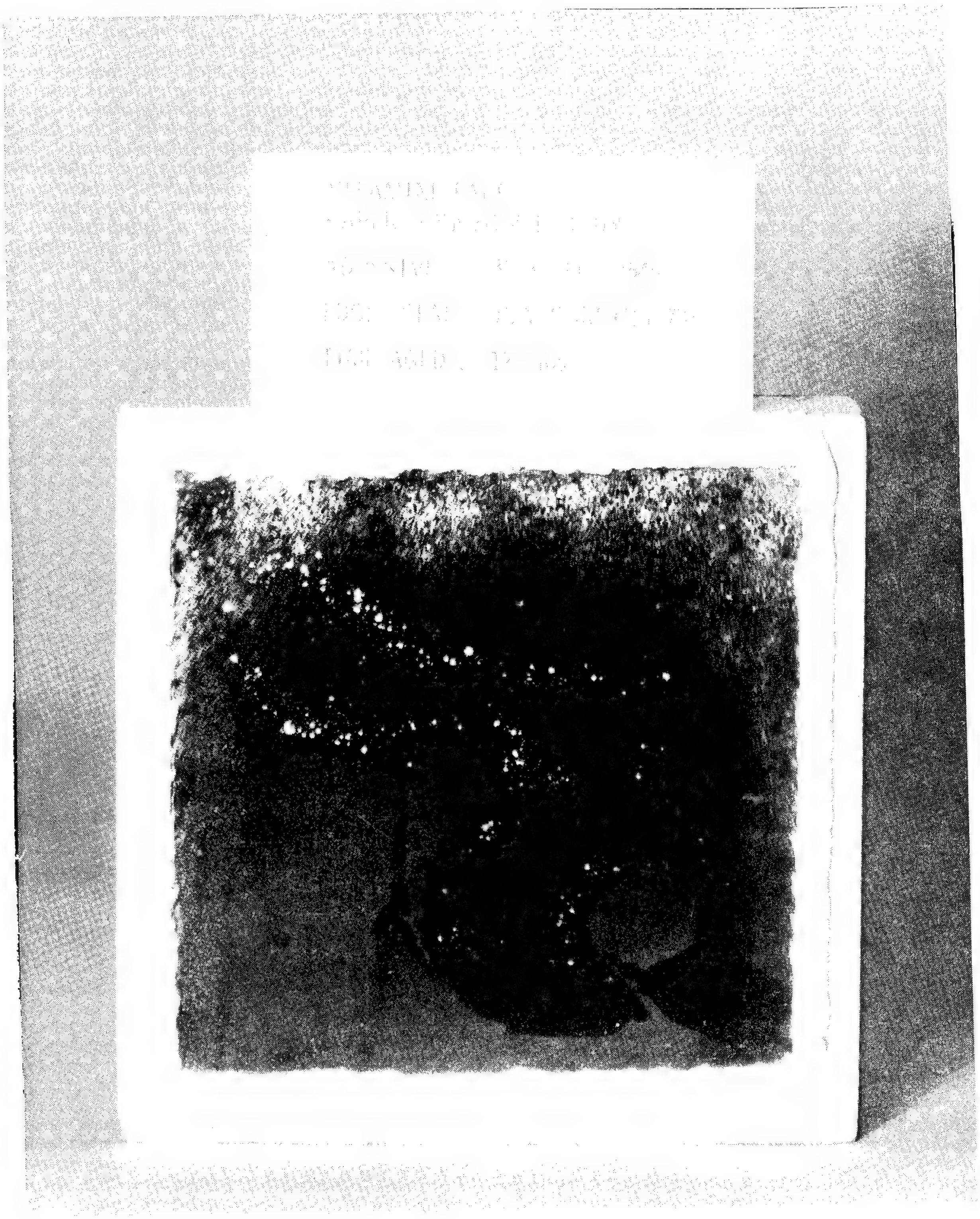


FIGURE 10

MELAMINE FACE
PAPER HONEYCOMB BODY

ADHESIVE : 3M's EC- 3549
EDGE SEAL : GE 1200 CONSTRUCTION SEALANT
TIME AGED : 12 mos.

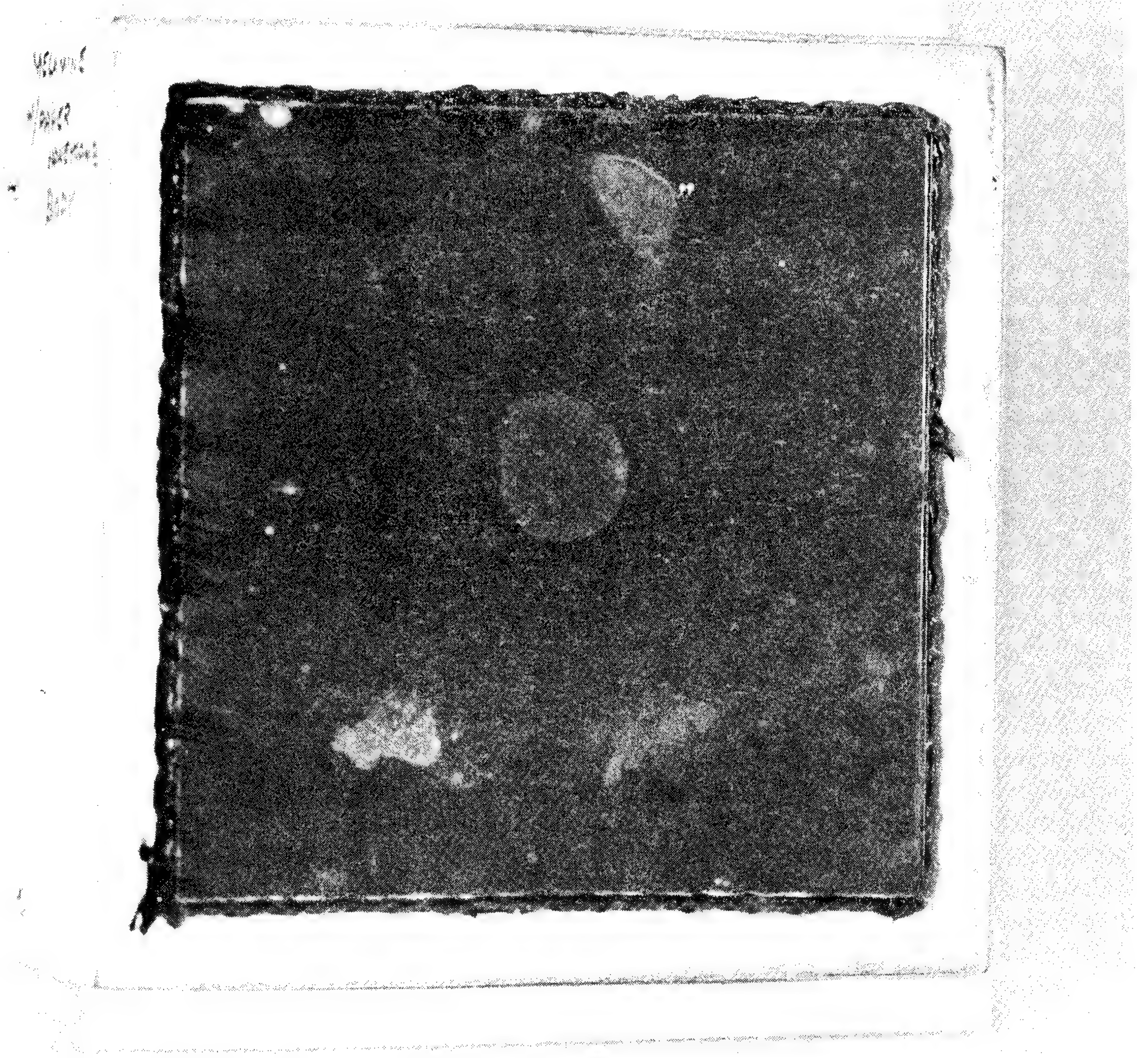


FIGURE 11

FIBERGLASS FACE
SINE WAVE FIBERGLASS BODY
ADHESIVE: 3M's EC- 3549
EDGE SEAL: GE 1200 CONSTRUCTION SEALANT
TIME AGED: 12 mos.

FIGURE 12

FIGURE 13

FIBERGLASS FACE
SINE WAVE FIBERGLASS BODY

ADHESIVE : 3M's EC-3549
EDGE SEAL : DOW CORNING 790 SEALANT
TIME AGED : 12 mos.

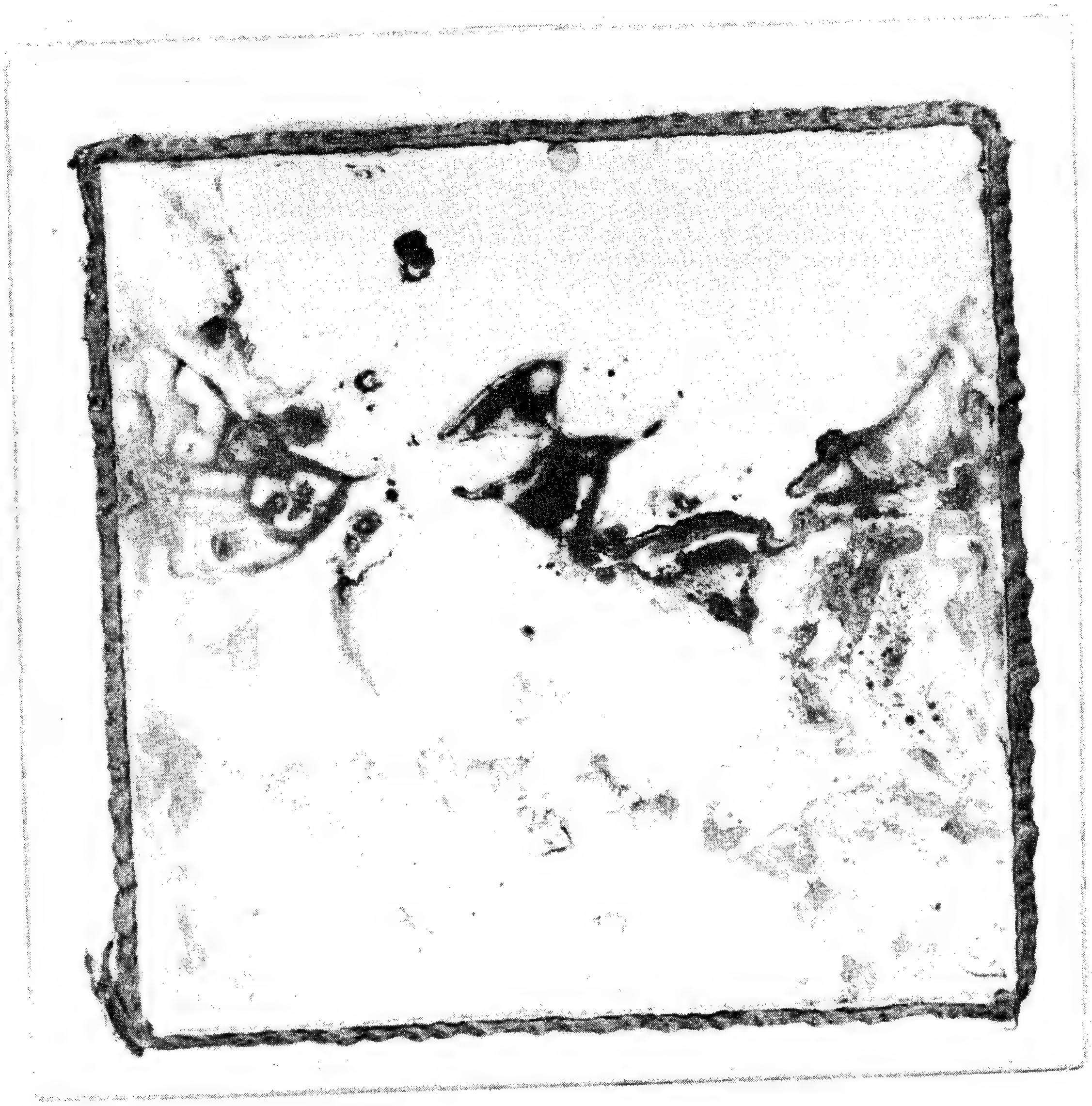


FIGURE 14

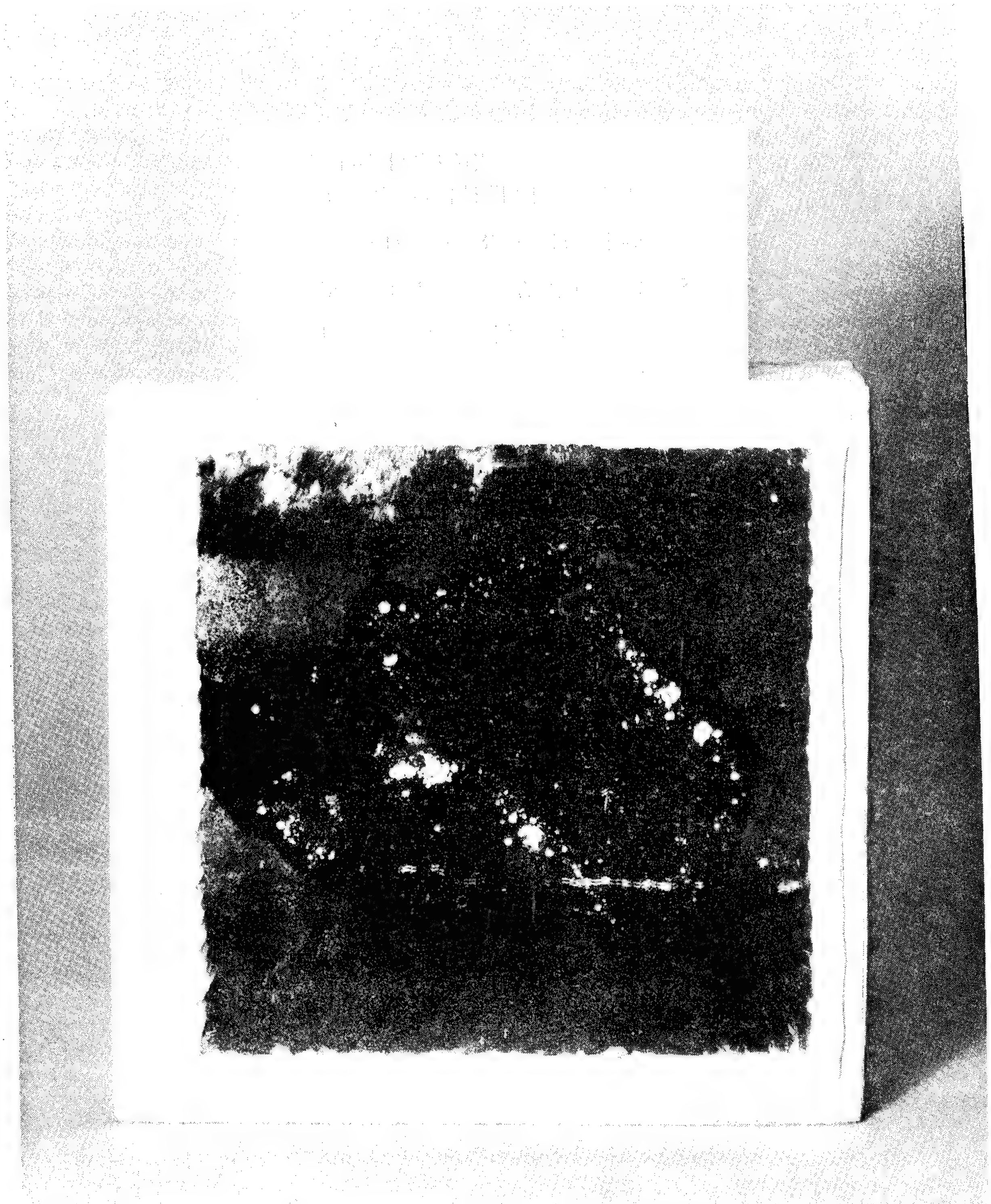


FIGURE 15

MELAMINE FACE
SINE WAVE FIBERGLASS BODY

ADHESIVE: 3M's EC- 3549
EDGE SEAL: DOW CORNING 790 SEALANT
TIME AGED: 12 mos.

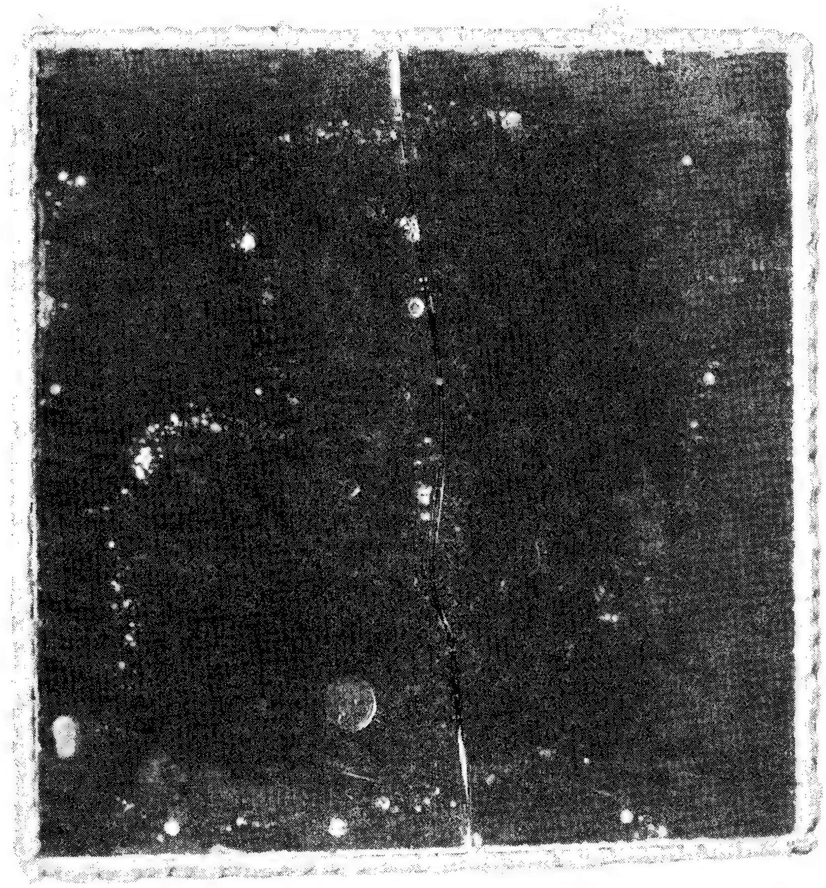


FIGURE 16

MELAMINE FACE
SINE WAVE FIBERGLASS BODY

ADHESIVE: 3M's EC-3549
EDGE SEAL: GE 1200 CONSTRUCTION SEALANT
TIME AGED: 12 mos.

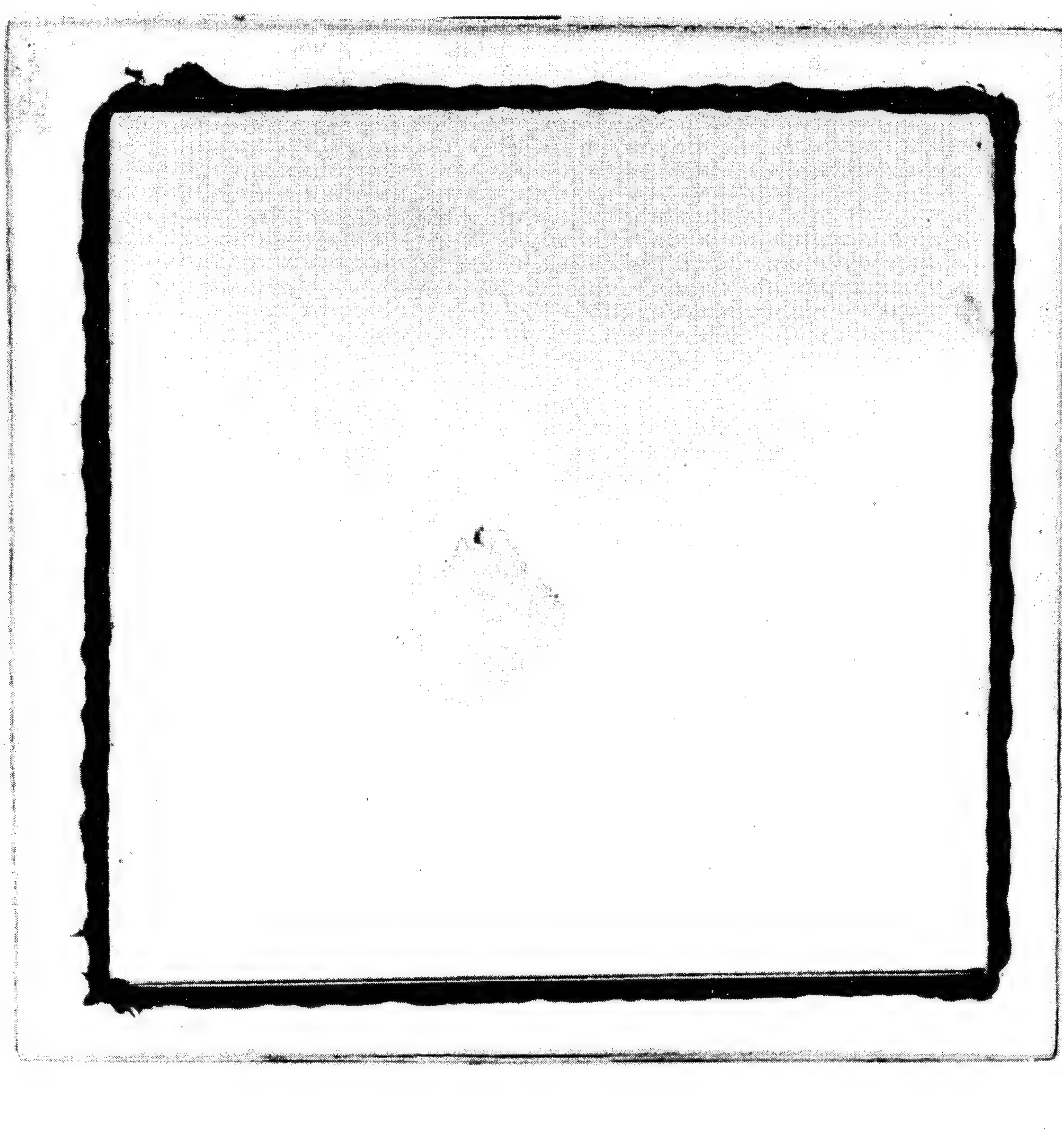
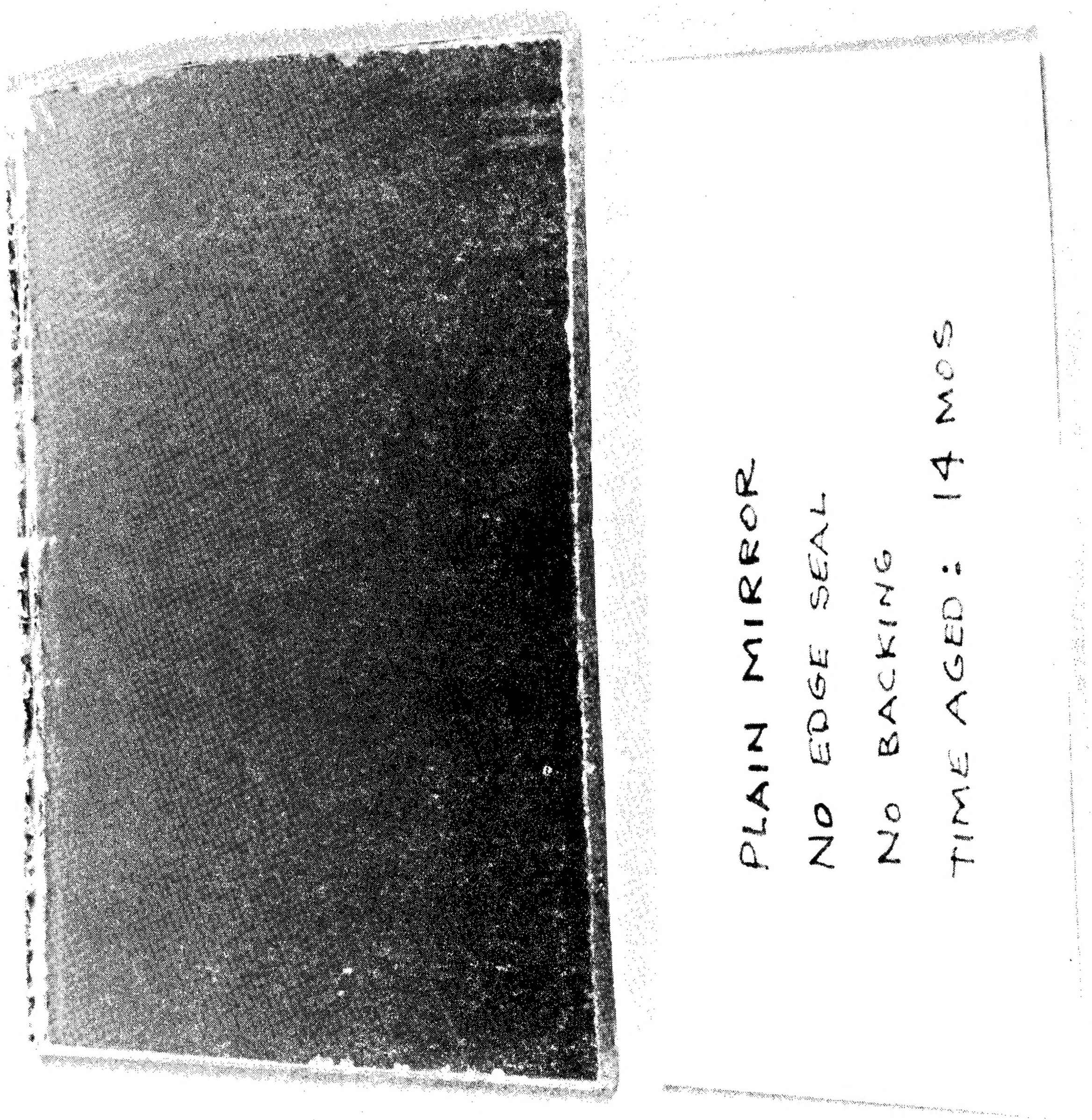
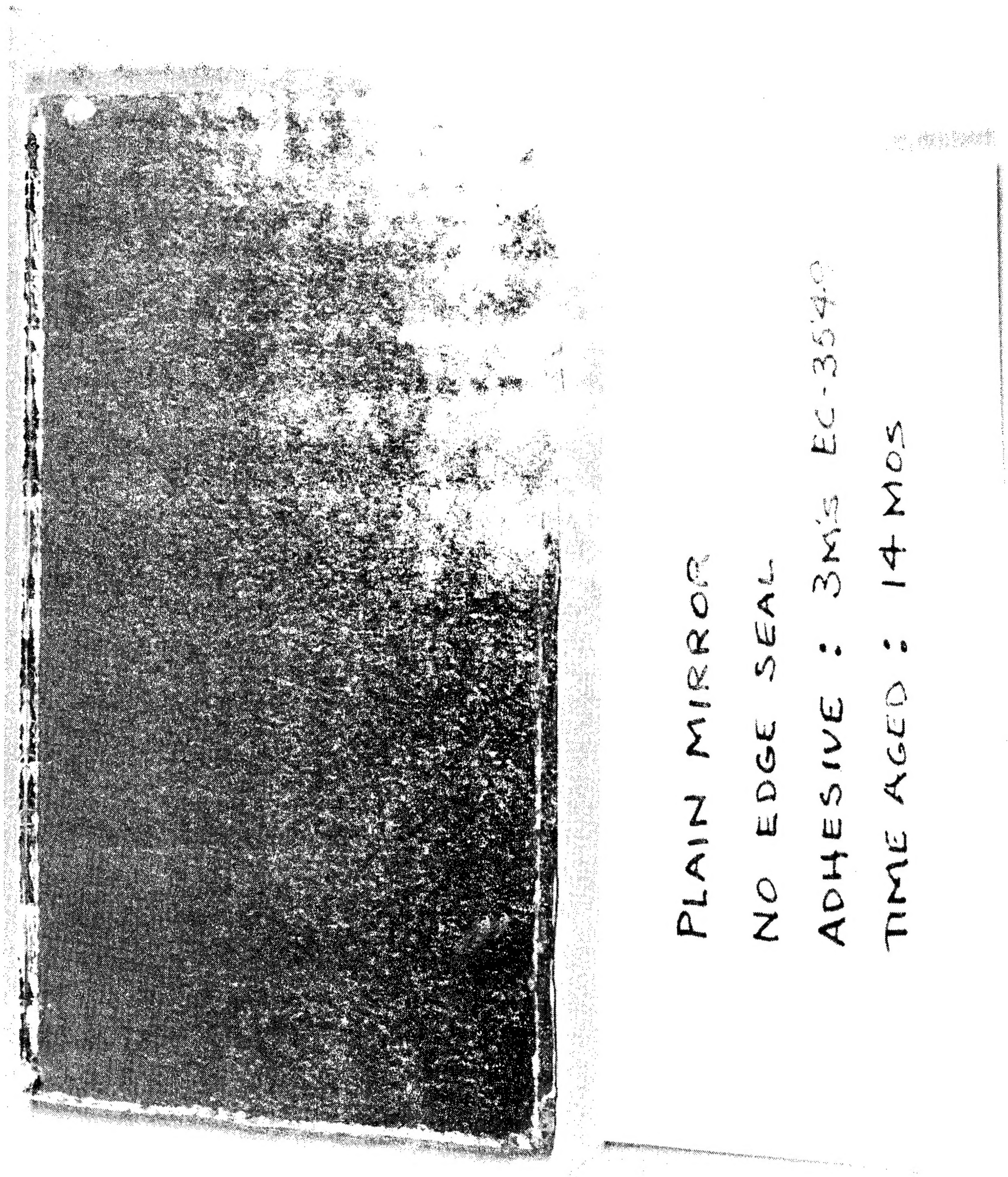


FIGURE 17




PLAIN MIRROR
NO EDGE SEAL
ADHESIVE : 3M'S EC-3540
TIME AGED : 14 MOS

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